RECENT (non)RESULTS OF LHC UPGRADE STUDIES

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- Local 2nd-Order Chromatic Correction of IR's 

- Combined-function doublet magnets close to IP 

Local 2nd-Order Chromatic Correction with $\beta^* = 25$ cm

$$\xi_2 = -\frac{1}{8\pi} \cdot \oint K_0 \cdot \Delta\beta_1 \cdot ds - \xi_1 \quad {}^{*1}$$

$$\Delta\beta_1(s) = \frac{\beta_0}{2\sin(2\pi\nu_0)} \cdot \int_s^{s+C} K_0(s') \cdot \beta_0(s') \cdot \cos[2\pi\nu_0 - 2\,|\,\psi_0(s') - \psi_0(s)\,|] \cdot ds'$$

- ξ_2 largest for ν_0 approaching 0 or 0.5
- ξ_2 smallest for phase advance between IP's $\Delta\psi = {}^{(2n+1)\pi}/_2$ (exact cancellation if IR optics are identical)

- The triplets are the largest source of ξ_2 in the ring (huge β's).

- Correcting ξ_2 is equivalent to eliminating the 1st order chromatic β-wave. Since $\Delta\beta_1$ advances as 2x the phase, with ~90° cells every 2nd sextupole per plane is near either the maximum or the minimum in the β-beat $\Rightarrow$ 2 sub-families of sextupoles per plane are sufficient (in principle) to kill $\Delta\beta_1$.

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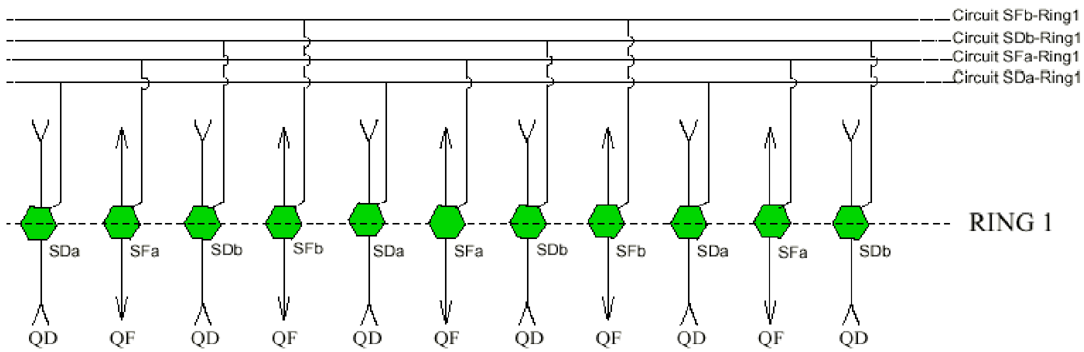
*1 T. Sen & Mike Syphers, "2nd Order Chromaticity of the Collider", IEEE proceedings, 1993.



INTERLEAVED SEXTUPOLE SCHEME

Extending the sextupole families as far as 18 cells each side of the IR failed to cancel $\Delta\beta_1$ for integrated sextupole strengths B"L less than ~8,000 $T.m/m^2$ (or thereabouts).

- CERN has an accepted <u>global</u> solution for ξ_2 cancellation[*2] with β^* = 25 cm — it requires every sextupole in the ring (342), 4 familes per octant per beam (64 families total), and 1500 $T.m/m^2$ maximum B"L. Vertical sextupole strengths come within 2% of this maximum.

[*2] Jean-Pierre Koutchoik, private communication, January 27, 2007, and see also the older discussion; "Second Order Chromaticity Correction of LHC at Collision", Stephane Fartoukh, LHC Project Report 308, 1999.

COMBINED-FUNCTION DOUBLET MAGNETS CLOSE TO THE IP

MOTIVATION & BACKGROUND INFO

- Early separation ~1 m dipoles ('D0') in slots ~3.5 & 6.8 m from the IP have been suggested as a means to increase luminosity by decreasing the crossing angle[*3].
- Thin doublet quadrupoles ~13 m from the IP ('Q0') have been claimed to modify the β functions such that, for $\beta^* = 25$ cm, β_{max} is no larger than for $\beta^* = 55$ cm[*4]. In this case the aperture & technology demands are diminished for upgraded triplet magnets.

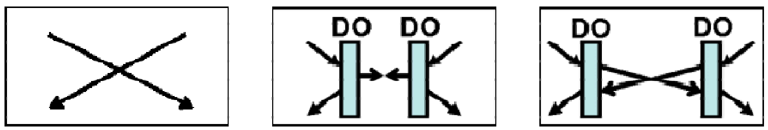
- The investigation into the feasibility of using gradient magnets in the 3.5 & 6.8 m slots was an effort to combine these 2 ideas.

[*3] J.P. Kartchouk & G. Serbini, "An Early Beam Separation Scheme for the LHC Luminosity Upgrade", LHC Project Report 972, 2006, and; "D0 and Its Integrability", presented at LUMI '06, Valencia, 2006.

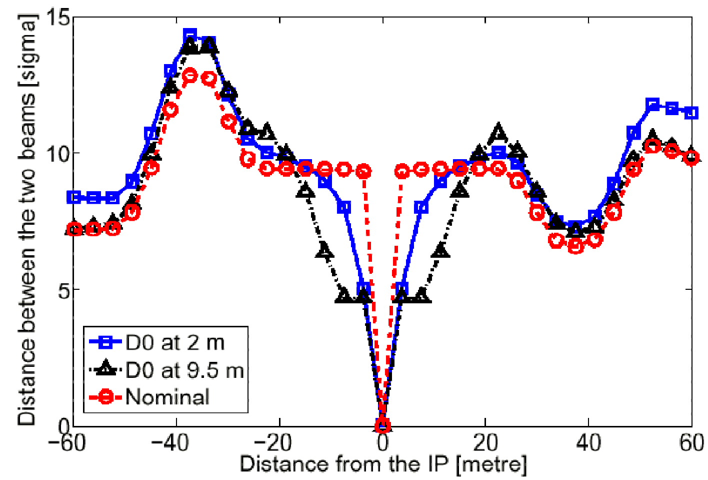
[*4] E. Laface, R. Ostojic, W. Scandale, D. Tommasin, C. Santoni, "Interaction Region with Slim Quadrupoles", EPAC proceedings, 2006; E. Laface, "Q0 with L*=13 m", presented at LUMI '06, Valencia, 2006.

D0 Separation Dipoles — basic concept:

- Increasing beam-beam interactions at a 'few' close parasitic crossings by decreasing the crossing angle is an acceptable trade-off to obtain large luminosity gains.



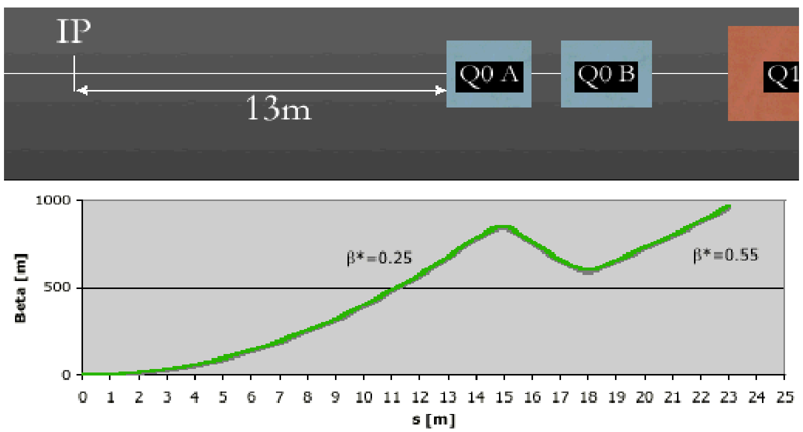
(a) (b) (c)

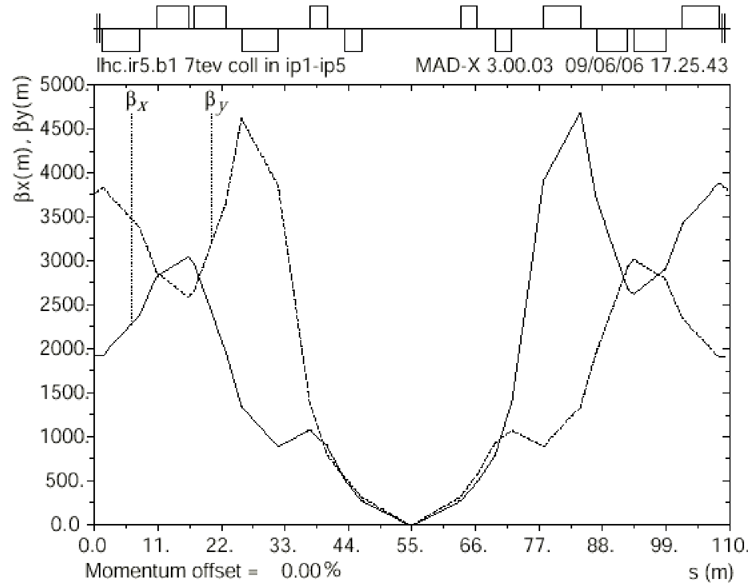


	$\beta^*[m]$	Integrated field $[T \cdot m]$	L/L_0
D0 at 2 m	0.25	6.1	5.7
	0.20	6.8	7.2
	0.15	7.9	9.5
D0 at 9.5 m	0.25	5.9 (6.8 if $n_b = 5616$)	4.6 (8.6)
	0.20	6.6 (7.6 if $n_b = 5616$)	5.2 (9.7)
	0.15	7.6 (8.7 if $n_b = 5616$)	5.9 (10.8)

Q0 Quadrupole Doublet — basic concept:

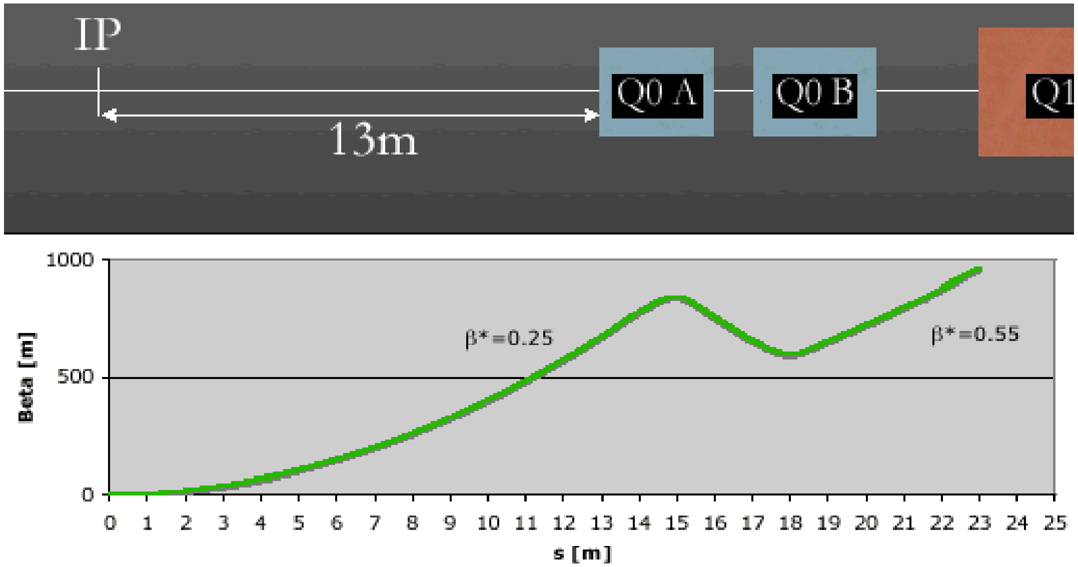
- An inner doublet allegedly alters the β growth curve for β* = 25 cm to match the β* = 55 cm curve (in one plane) entering the triplet. β_{max} in the triplet does not exceed the β* = 55 cm value in either plane.





Magnet	Length	Gradient	Min. diameter
SQ1	∼ 3 m	∼ 118 T/m	> 32 mm
SQ2	∼ 3.5 m	∼ 163 T/m	> 35 mm

A Note on Transforming the β Growth from β* = 25 cm to the β* = 55 cm Growth Curve via 'Q0' Inner Quadrupoles†



For β* = 25 cm: at 14.5 m: β = 841.250 m, α = -58.000

For β* = 55 cm: at 18.0 m: β = 589.641 m, α = -32.727

at 23.0 m: β = 962.368 m, α = -41.818

$$\beta(S) \approx \beta_i \cdot \left(1 - {}^{\alpha_i}\!/_{\beta_i} \cdot S\right)^2$$

† Quad locations & β functions pilfered from Emanuele Laface's "Q0 with L*=13 m" presentation at LUMI '06, Valencia, 2006.

A thin lens of inverse focal length q_1 14.5 m from the IP changes α by $\Delta\alpha = q_1 \cdot \beta_1$.

To change the β^* = 25 cm curve at 14.5 m to intersect β^* = 55 cm at 18 m α_1 must be:

$$\alpha_1 \approx \frac{841.25}{3.5} \cdot \left(1 - \sqrt{\frac{589.641}{841.250}}\right) = 39.129$$

$$q_1 = \frac{\Delta\alpha_1}{\beta_1} = \frac{(39.129 + 58.000)}{841.25} = +0.11546 m^{-1}$$

At 18 m β is now = 589.641 m, and $\alpha_2 = \alpha_1 - \gamma_1 \cdot \Delta S = 32.755$

Another thin lens q2 corrects α to match the β^* = 55 cm curve:

$$q_2 = \frac{\Delta\alpha_2}{\beta_2} = -\frac{(32.755 + 32.727)}{589.641} = -0.11105 m^{-1}$$

At 7 TeV/c $B_0\rho = 7 * 3335.64$ T·m, so the integrated gradients of the 2 thin lenses are:

$$\boxed{\begin{aligned} G_1 L &= q_1 \cdot B_0 \rho = +2695.9 \ldots \, {}^{T \cdot m}/_{m} \\ G_2 L &= q_2 \cdot B_0 \rho = -2593.1 \ldots \, {}^{T \cdot m}/_{m} \end{aligned}}$$

For L = 3.5 m, $G_{1,2}$ ~ 750 $^{T}/_{m}$!

SUMMARY & COMMENTS

- For β^* = 25 cm, local 2nd order chromatic compensation of the IR's does not appear possible for any 'reasonable' values of sextupole strengths. (This has implications for 'dipole first' IR upgrade models since βmax is ~2x larger in the triplets).

- The notion of a D0/Q0 combined function doublet situated close to the IP is a dead end. Far worse, the Q0 doublet proposal (which has attracted a large following in the international community) has been discovered to be complete nonsense. [This has an impact on BNL, which has eagerly anticipated building these quads!]

  There *might* be some value in exploring the impact of a single, long, weak quad inboard of the triplet, but this isn't at all clear at this point....

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